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(54) **FABRIC HAVING ULTRAVIOLET
RADIATION PROTECTION, ENHANCED
RESISTANCE TO DEGRADATION, AND
ENHANCED RESISTANCE TO FIRE**

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(57) **ABSTRACT**

A method for treating a fabric for ultraviolet radiation pro-
tection, enhanced resistance to degradation, and enhanced
resistance to fire is disclosed which comprises the steps of
adding zinc oxide nanoparticles to a solution of 3-glycidy-
loxypropyl-trimethoxysilane, placing a fabric in the mixture
of zinc oxide particles and 3-glycidyloxypropyl-trimethox-
ysilane, curing the fabric, and washing the fabric. Other meth-
ods of treating a fabric are disclosed.

17 Claims, No Drawings

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**FABRIC HAVING ULTRAVIOLET
RADIATION PROTECTION, ENHANCED
RESISTANCE TO DEGRADATION, AND
ENHANCED RESISTANCE TO FIRE**

**CROSS REFERENCE TO RELATED
APPLICATIONS**

This application is a continuation-in-part of U.S. patent application Ser. No. 14/245,152 filed on Apr. 4, 2014, which was a continuation of U.S. patent application Ser. No. 13/632,223 filed on Oct. 1, 2012, which is now U.S. Pat. No. 8,690,964, which was a continuation-in-part of U.S. patent application Ser. No. 13/317,152 filed on Oct. 11, 2011, which is now U.S. Pat. No. 8,277,518.

BACKGROUND

This disclosure relates to a fabric having ultraviolet radiation protection, and more specifically, to a fabric having ultraviolet (UV) radiation protection incorporated into the fabric. Further, this disclosure relates to a fabric having enhanced ability to resist degradation of the fabric. The disclosure also provides methods to provide enhanced resistance to color degradation of a fabric and enhanced resistance to fiber strength degradation of a fabric. This disclosure provides methods to provide enhanced resistance to fire of a fabric.

Ecological friendly fabrics or Eco-friendly fabrics are gaining in popularity and use in clothing. An Eco-friendly fabric may be a natural fiber such as cotton, hemp, or bamboo which has been grown in soil that has not been treated with pesticides for a number of years. Some examples of other Eco-friendly fabrics are organic cotton, sisal, a combination of hemp and recycled rayon, a combination of hemp and cotton, broadcloth, denim, linen, and a combination of bamboo and recycled rayon. Natural fibers, which may be derived from plants or animals, such as wool, angora, silk, alpaca, cashmere, and silk are also examples of Eco-friendly fabrics. Synthetic fabrics, which may be made from synthetic sustainable products, such as nylon, rayon, olefin, spandex, acrylic, and tencel are also examples of Eco-friendly fabrics.

To assist an individual in determining whether a garment has protection against ultraviolet radiation, a rating system has been developed. This rating system is known in the industry as the UPF (Ultraviolet Protection Factor) rating system. Clothing having a rating of UPF 50 are able to block out 98% of the sun's ultraviolet radiation. Further, by way of example, a garment having a rating of UPF 15-24 will only block out 93.3% to 95.9% of ultraviolet radiation. Exposure to the sun's harmful ultraviolet radiation (known as UVA/UVB rays) can damage the skin, can cause sunburn, and can lead to skin cancer over prolonged exposure.

There are a number of factors that affect the level of ultraviolet radiation protection provided by a fabric and the UPF rating. Some factors are the weave of the fabric, the color of the fabric, the weight of the fabric, the fiber composition of the fabric, the stretch of the fabric, moisture content of the fabric. If the fabric has a tight weave or a high thread count then the fabric will have a higher UPF rating. However, even though the fabric has a higher UPF rating, the fabric may be less comfortable because a tighter weave or higher thread count means that the fabric is heavy or uncomfortable to wear. Another factor that affects protection is the addition of chemicals such as UV absorbers or UV diffusers during the manufacturing process. As can be appreciated, some of the features that make a garment comfortable to wear also make the gar-

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ment less protective. A challenge for a clothing manufacturer is to provide clothing having both protection from the sun and being comfortable to wear.

Ultraviolet light exposure causes degradation in natural and synthetic fabrics, mainly due to the breakage of the polymer chains. The smaller polymer chains have a lower mechanical strength which in turn significantly reduces the overall strength of the fibers or the fabric. In addition, the UV light can cleave or oxidize the dye molecules which results in the loss of color over time. Once fabric or clothing degrades over time, the fabric or clothing may have to be discarded due to the appearance of the fabric or clothing. Due to degradation of the fabric or clothing, the fabric or clothing may not have been worn for an acceptable period of time. If the clothing was expensive, being only able to wear the clothing for a short period of time will not be acceptable to the wearer or purchaser of the clothing. The wearer or purchaser may not purchase the same brand in the future due to the problem encountered with the previous purchase. It is also known that ultraviolet light exposure causes color degradation in natural and synthetic fabrics. Once the color or colors in fabric or clothing degrades, the fabric or clothing may have to be discarded due to the unacceptable appearance of the fabric or clothing.

Additives to fabric, such as TiO₂, can absorb UV light to lower the photo-degradation of the polymer and dyes. However, upon absorption of the UV light, the surface of TiO₂ particles become catalytically active due to production of an electron-vacancy pair. The produced electrons and radicals attack the polymer around the particle surface and cause it to cleave, which can propagate crack in the fiber. In fact, the surface photo-reactive property of TiO₂ is successfully used to destroy pollutant molecules in the residential air purifiers. In the presence of moisture and oxygen, the photo-degradation activity of TiO₂ further increases due to the participation of H₂O and O₂ molecules in the cleavage, oxidation, and hydrolysis of the polymer molecules. In view of this, treating a fabric with an additive such as TiO₂ should be avoided in order to allow the fabric not to prematurely degrade.

Fabric and clothing are also known to be highly flammable. In order to reduce the flammability of fabric or clothing, a flame retardant product is applied to the fabric or clothing. However, a large amount of flame retardant product needs to be incorporated into the fabric or clothing to make the fabric or clothing effective in decreasing the flammability of the fabric or clothing. This may be acceptable for use in specialized clothing, such as clothing for a fireman, but is unacceptable for daily wear or clothing. Clothing having a large amount of flame retardant product in it may not sell due to the appearance or feel of the clothing. In this event, treating clothing with a large amount of flame retardant product may not occur.

Therefore, it would be desirable to provide a fabric that does not prematurely degrade, in both color and fiber strength, over time. It would also be advantageous to provide a fabric that incorporates enhanced resistance to fire or flames. It would also be desirable to provide a fabric that can be treated to protect an individual from the effects of the sun. Moreover, there is a need for a controllable process for attaching UV protection to a fabric after the fabric has been manufactured so that the treated fabric may be used to protect an individual from UV radiation and to enhance the resistance to degradation of the fabric. Furthermore, it would be advantageous to incorporate adequate protection in a garment, fabric, or textile to protect against exposure to UV radiation, to increase the UV resistance of a garment, fabric, or textile, or to enhance UV radiation absorption of a garment, fabric, or

textile to protect an individual from UV radiation, and also to be able to enhance the resistance to degradation of the garment, fabric, or textile.

BRIEF SUMMARY

In one form of the present disclosure, a method for treating a fabric for ultraviolet radiation protection, enhanced resistance to degradation, and enhanced resistance to fire is disclosed which comprises the steps of adding zinc oxide nanoparticles to a solution of 3-glycidyloxypropyl-trimethoxysilane, placing a fabric in the mixture of zinc oxide particles and 3-glycidyloxypropyl-trimethoxysilane, curing the fabric, and washing the fabric.

In another form of the present disclosure, a method for treating a fabric for ultraviolet radiation protection, enhanced resistance to degradation, and enhanced resistance to fire comprises the steps of adding zinc oxide nanoparticles to a solution of 3-glycidyloxypropyl-trimethoxysilane, adding 1-methylimidazol to form a suspension, stirring the suspension, dipping a fabric into the suspension, and curing the fabric.

In yet another form of the present disclosure, a method for treating a fabric for ultraviolet radiation protection, enhanced resistance to degradation, and enhanced resistance to fire is disclosed which comprises the steps of adding zinc oxide nanoparticles into a solution of 3-glycidyloxypropyl-trimethoxysilane, sonicating the mixture of zinc oxide nanoparticles, adding 1-methylimidazol to form a suspension, sonicating the suspension, and transferring the suspension into a spray bottle.

The present disclosure provides a fabric having ultraviolet radiation protection which is lightweight and can be worn in any temperature.

The present disclosure provides a fabric having ultraviolet radiation protection which provides enhanced protection from both UVA and UVB radiation when worn by an individual.

The present disclosure also provides a fabric having ultraviolet radiation protection which retains ultraviolet radiation protection after use or after cleaning.

The present disclosure provides a fabric having ultraviolet radiation protection which is comfortable to wear.

The present disclosure provides a fabric having antimicrobial protection incorporated therein.

The present disclosure also provides a fabric having ultraviolet radiation protection which can be manufactured without increasing the cost of the fabric.

The present disclosure provides a fabric having ultraviolet radiation protection that may be incorporated into the fabric by use of a laundry additive.

The present disclosure is also directed to a fabric having enhanced resistance to degradation of the fabric.

The present disclosure is further directed to a fabric having enhanced resistance to fire or flames.

The present disclosure also provides a fabric having ultraviolet radiation protection, enhanced resistance to fiber strength degradation, enhanced resistance to color degradation, and enhanced resistance to fire.

The present disclosure provides a fabric having ultraviolet radiation protection that is incorporated into active wear clothing or athletic clothing.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Various methods or processes are disclosed herein for the immobilization of UV-blocking nanoparticles on Eco-

friendly fabric to incorporate UV protection in the fabric. Once the UV-blocking nanoparticles are attached, the Eco-friendly fabric will be able to protect a wearer of the fabric from UV radiation. One method comprises direct immobilization from in situ formation of the particles. A second method comprises carboxylation or phosphorylation of the fabric followed by binding of the UV-blocking nanoparticles to the modified fabric. A third method comprises modifying UV-blocking nanoparticles with a self-assembled monolayer (SAM) or polymer layer containing an active chemical group capable of binding to the fabric and deposited on the fabric from solution.

ZnO (zinc oxide) nanoparticles are generally formed by the precipitation of a zinc salt (acetate, sulfate, nitrate, chloride) using either aqueous hydroxide or an amine. The following examples disclose direct immobilization from in situ formation of the ZnO nanoparticles.

Example 1

Solution Sol-Gel Process, Hydroxide Base

4.39 g. zinc acetate (20 mmol) is dissolved in 100 mL deionized or distilled water. A textile is added to this solution and 100 mL 0.4M NaOH is added while mixing. The suspension is mixed for 2 hours to form a suspension of zinc oxide nanoparticles in contact with the fabric. The textile is removed from the nanoparticle suspension and laundered in a household washing machine. As can be appreciated, a fabric may be treated to have ultraviolet radiation protection incorporated in the fabric by the steps of dissolving zinc acetate or other zinc salt in a liquid to form a solution containing Zn(II) ions, adding a fabric to the solution, mixing the solution and the fabric, and adding a base to the solution when the solution and the fabric are being mixed to form a suspension of zinc oxide nanoparticles in contact with the fabric.

Example 2

Solution Sol-Gel Process, Amine Base

4.39 g. zinc acetate (20 mmol) is dissolved in 100 mL deionized water. A textile is added to this solution while mixing and 40 mmol amine is added while mixing. Amines used may include ethanolamine, ethylenediamine, (tris)hydroxymethylaminomethane, or others. The textile is removed from the nanoparticle suspension and laundered in a household washing machine.

Example 3

Mechanochemical Process

5.75 g. zinc sulfate heptahydrate (20 mmol) and 0.88 g (15 mmol) sodium chloride are powdered finely and blended, then placed with a textile in a ball mill or similar mechanical mixer. 1.6 g (40 mmol) sodium hydroxide is powdered and added to the mixer. After twenty minutes, the textile is removed and rinsed thoroughly with water.

The following examples disclose carboxylation or phosphorylation of the fabric followed by binding of the UV-blocking nanoparticles to the modified fabric.

Example 4

Modification of Textile with Phosphonic Acid Groups

For this process it will be necessary to modify a textile with phosphonic acid groups. This can be accomplished in a num-

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ber of ways, but it is desirable to use materials that are non-toxic and/or renewably sourced chemicals. Phosphorylated cellulose should form covalent linkages with ZnO and TiO₂ nanoparticles. The interaction between phosphonates and oxide surfaces are used for modification of the oxide surfaces. In essence, the procedure consists of condensing the cellulose textile with a bis(phosphonic acid), phosphonate, or phosphate species, either organic or inorganic. Urea may be added to forestall discoloration of the textile. Phosphorylation takes place driven by the elimination of water. The resulting phosphorylated textile will directly bind both zinc oxide and titanium oxide nanoparticles. It will be necessary to restrict the degree of phosphorylation of the textile to prevent great alteration in the properties of the textile by controlling a reaction time. This process does not require in situ synthesis of the zinc oxide nanoparticles. Commercially available zinc oxide nanoparticles may be used.

A sample of cotton textile is wetted with a 10% v/v solution of phosphoric acid or bis-phosphonic acid containing 10-30% w/v urea. The textile is pressed to remove excess solution and baked in an oven at 85-100° C. for 5 minutes to dry, then at 170° C. for 2-4 minutes to cure unreacted groups. The textile is removed from the oven and washed with water. The textile is then used without further modification in subsequent deposition steps.

Example 5

Modification of a Textile by Partial TEMPO-H₂O₂ Oxidation

A sample of cotton textile (ca. 1 g) is added to a solution composed of 90 mL water with 10 mg (0.065 mmol) TEMPO and 0.22 g (2 mmol) sodium bromide. Hydrogen peroxide 3% is added (0.9 mL, 1 mmol) and the reaction stirred at RT for 10 minutes to 2 hours. The material is washed with water, dried, and used without further modification in the following ZnO deposition step.

Example 6

Immobilization of Nanoparticles on a Phosphorylated or Carboxylated Cellulose Surface

Ca. 1 mg/mL nanoparticles are suspended in water, ethyl alcohol, or other solvent. The phosphorylated or carboxylated

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cellulose textile is added to the suspension and the suspension is gently mixed over a reaction period of 1 to 12 hours. The textile is removed from the suspension and subjected to tumble drying or another drying procedure to force surface condensation and cure remaining groups.

The following example discloses modifying UV-blocking nanoparticles with a self-assembled monolayer (SAM) or polymer layer containing an active chemical group capable of binding to the fabric and deposited on the fabric from solution.

Example 7

Grafting to Attachment of Cellulose to Nanoparticles Through Reactive Groups

In this method, ZnO particles are synthesized separately by any of the means discussed in Examples 1-3 or the ZnO particles may be purchased commercially. The ZnO particles are suspended in water or a weak non-nucleophilic aqueous buffer and an organosilane or phosphonate with one of the given combinations of reactive groups, as shown in Table 1, is added. Multidentate ligand or polymeric silanes may also be added to this mixture to facilitate the formation of a durable reactive layer and an oxide, alkoxide, or salt of another metal such as Ti or Si may be added first to form a surface layer of another oxide in the ZnO particles. After a reaction time of 1 to 12 hours, the particles are collected by centrifugation and washed with water. The particles are then resuspended in water or buffer and added to the textile. The conditions for binding of the particles to the textile vary depending on the headgroup, as shown in Table 1, but may involve direct application of the particles to the textile similarly to the process disclosed in Example 6, raising the pH of the suspension containing the textile, or heating the textile either in or after removal from the suspension. This process has the advantage of yielding extremely fine control over the nature of the linkage between particle and textile. This process has a further advantage in that the treated textile will be durable due to the robustness of self-assembled siloxane layers on oxide.

TABLE 1

Molecule name (if commercially available)	Linker	Headgroup	Commercially available?
3-glycidoxypropyl-triethoxysilane	Triethoxysilane	Glycidyl ether	Yes
2-(3,4-cyclohexyloxy)ethyltriethoxysilane	Triethoxysilane	Cyclohexyl oxide	Yes
Hydroxymethyl-triethoxysilane	Triethoxysilane	Hydroxymethyl	Yes
Isocyanatopropyl trimethoxysilane	Trimethoxysilane	Isocyanate	Yes
Bis(triethoxysilyl) ethane	Triethoxysilane (2)	N/A	Yes
6-azidosulfonylhexyl triethoxysilane	Triethoxysilane	Azidosulfonyl	Yes
	Triethoxysilane	Vinylsulfone	No
	Triethoxysilane	Aryl azide	No
	Phosphonate	Glycidyl ether	No
	Phosphonate	Cyclohexyl oxide	No
	Phosphonate	Azidosulfonyl	No
	Phosphonate	Vinylsulfone	No
	Phosphonate	Aryl azide	No
Bis(triethoxysilyl)	Triethoxysilane (2)	Secondary amine	Yes

TABLE 1-continued

Molecule name (if commercially available)	Linker	Headgroup	Commercially available?
propylamine APTES/EGDE	Triethoxysilane	Amine/Ethylene glycol diglycidyl ether	Yes, 2 components

The terms “fabric” or “textile” are intended to include fibers, filaments, yarn, textiles, material, woven and non-woven fabric, knits, and finished products such as garments. The methods described above may be used in treating fibers, filaments, yarn, textiles, and fabrics. For example, fibers may be initially treated by use of one or more of the above disclosed methods and the fibers may be manufactured into a fabric or a textile. Once manufactured into a fabric, the fabric may be treated by use of one or more of the disclosed methods. In this manner, individual fibers and the entire fabric are treated to incorporate UV protection. As can be appreciated, the treated fabric may be used to manufacture a garment such as, by way of example only, shirts, pants, hats, coats, jackets, shoes, socks, uniforms, athletic clothing, and swimwear. It is also possible and contemplated that the treated fabric may be used to construct non-apparel items such as blankets, sheets, sleeping bags, backpacks, and tents.

Further, it is also possible to further modify ZnO particles with a thin layer of other oxides in a “core-shell” type procedure by adding a reactive precursor to a suspension of the ZnO oxides. Oxides that can be deposited in this manner include SiO₂ from tetraethoxysilane (TEOS) or sodium silicate, and Al₂O₃ and TiO₂ either from the appropriate alkoxides, aluminate/titanate compounds, or other hydrolyzable aluminum or titanium compounds. A second oxide shell of this type may enhance the formation and stability of both directly applied ZnO-textile conjugates and those formed by modification of nanoparticles with an organic monolayer. ZnO can also be modified by the addition of a multidentate silane along with a silane containing the desired functional group. The multidentate silane yields a more densely crosslinked siloxane surface than monodentate silanes alone, forming a more stable layer on ZnO.

Although the above examples and methods are applicable to the manufacturing process in which ultraviolet radiation protection is incorporated into the fabric, textile, or garment when initially produced, the following discloses various methods of incorporating ultraviolet radiation protection directly to clothing being laundered. By use of the following methods, a garment after purchase may be made a protected garment by an end user.

In general, the methods may comprise the self-assembly of certain polyanionic materials onto a ZnO surface to create a linker which will bind the particles to a cellulose (cotton) surface. Several acidic or oxyanion functional groups are capable of self-assembly onto ZnO. These functional groups include siloxane, silanol, carboxylic acid, carboxylate, phosphonic acid, phosphonate, boronic acid or other groups capable of binding to oxide layers. Boronic acid is capable of forming very strong interactions with carbohydrates, including the glycosidically linked glucose units making up cellulose. One method or approach is to prepare a polymer bearing boronic acid groups and use that polymer to bind ZnO to cotton.

Various methods or processes are disclosed herein for the treatment of fabric to incorporate UV protection in the fabric by use of a laundry additive. One method is identified as the

cellulose-to-oxide method. A second method is termed the oxide-to-cellulose method. A third method is described as the free mixing method.

Example 8

The Cellulose-to-Oxide Method

In this method, cotton garments are pre-treated with boronic acid polymer resulting in cloth or fabric coated with boronic acid groups capable of binding to suspended uncoated ZnO particles. A home washing machine having the capability of adding a substance on a delayed basis may be used. In particular, boronic acid polymer is added to laundry detergent or added at the beginning of the laundry cycle. A suspension of ZnO particles may be added to a compartment in the washing machine that will dispense the particles on a delayed basis. For example, several washing machines have a compartment for storing bleach which is dispensed later on in the laundry cycle. The suspension of ZnO particles may be placed in the bleach compartment to be dispensed at the time that bleach would normally be dispensed into the washing machine. The washing machine would initially mix the clothing with the boronic acid material. This will result in the clothing bearing boronate groups. At the end of the delayed period the washing machine will dispense the suspension of ZnO particles into the washing machine. The ZnO particles will bind to the boronate groups and become attached to the clothing. It is also possible and contemplated that the suspension of ZnO particles may be manually added to the washing machine in a delayed manner. Manually adding the suspension may be required if the washing machine is not equipped with a compartment for adding bleach on a delayed basis.

Example 9

Oxide-to-Cellulose Method

In this method, ZnO particles are treated with boronic acid polymer. Once prepared, these particles may be either mixed with laundry detergent and distributed in that form or sold as a separate additive that may be added to laundry detergent. The particles mixed with the laundry detergent or the separate additive is used in the washing machine as normal. During the course of the wash cycle, the boronic acid groups attach to the ZnO particles would assemble on and bind to cotton or other cellulose clothing. This results in a ultraviolet protected garment.

Example 10

Free Mixing Method

In this method, boronic acid polymer and ZnO particles (untreated) are incorporated into the laundry detergent preparation in the solid phase. When added to a laundry cycle or wash cycle the detergent and water will solubilize these materials causing boronic acid polymer to assemble on both ZnO

and cellulose. This will result in linked ZnO material. This method may require more boronic acid polymer and ZnO particles then the more controlled methods disclosed in Examples 8 and 9 to yield adequate grafting densities of ZnO on clothing.

Use of any of the methods disclosed in Examples 8, 9, or 10 will result in ZnO particles being bound to the fabric that is being washed in a conventional household washing machine. Once the ZnO particles are bound to the fabric, the fabric will have incorporated therein ultraviolet radiation protection. It is also possible and contemplated that the various methods described in Examples 8, 9, and 10 may be used more than once to incorporate ultraviolet radiation protection into clothing. For example, clothing may be treated by use of one or more of these methods and over time and after numerous washings the ultraviolet radiation protection may diminish. If there is any concern about the ultraviolet radiation protection of the garment, the garment may be washed using the various methods discussed in Examples 8, 9, and 10. Further, it is possible that a consumer may purchase a garment that has been treated using the methods described in Examples 1-7. Again, over time the ultraviolet radiation protection of the garment may decline. The consumer may use the methods disclosed in Example 8, 9, and 10 to wash the garment to again incorporate ultraviolet radiation protection into the garment.

All synthetic material such as polyester and nylon that is used in the manufacture of athletic clothing or active wear clothing may be rendered UV-absorbing using a ZnO preparation. These types of fabrics may resist treatment using the methods as outlined with respect to Examples 8, 9, and 10. One solution to this problem is to prepare ZnO particles coated with functional groups capable of being grafted directly to polyester or nylon materials. This may be accomplished by using benzophenone photografting chemistry. The following examples and methods are applicable to the manufacturing process in which ultraviolet radiation protection is incorporated into the artificial or synthetic fabric, textile, or garment when initially produced.

The following methods provide for the direct grafting of ZnO particles to nonpolar, non-natural polymers such as nylon and polyester. Nylon and polyester have little in the way of chemical functionality, containing only aliphatic and aromatic C—H bonds and amide or ester linkages between monomers. The method is capable of directly functionalizing C—H bonds. The following method describes preparing ZnO particles coated with functional groups capable of being grafted directly to polyester or nylon materials by using the photografting reaction of benzophenone.

Example 11

Grafting ZnO onto Artificial or Synthetic Fibers

In this method, an artificial fabric composed of polyester, nylon, or other polymer lacking hydroxyl functional group is modified by use of a preparation of a zinc oxide particle modified with a layer of reactive groups capable of C—H activation. Examples of the reactive functional group capable of C—H activation are benzophenone, sulfonylazides, aryl azides, or diazonium salts. The prepared particles are coated onto the fabric and a reaction is initiated using UV light, heat, or both. By way of example only, a mercury-vapor UV lamp may be used and the time for exposure may be one hour. Unbound particles are washed off the fabric. This second step, a curing step, bonds the prepared particles to the fabric. This method adds a second UV-absorbing chromophore

which cross-links and becomes further bonded to the polymer surface of the fabric upon exposure to UV light. In this method, zinc oxide particles can be composed of pure zinc oxide or zinc oxide coated with aluminum, titanium, or silicon oxides in a core-shell configuration. The result is an artificial fabric with photografted zinc oxide particles.

By way of example, the zinc oxide particles were prepared in the following manner. Five grams of zinc oxide nanoparticles were used and suspended in a solution of 98% ethyl alcohol. Two grams of benzophenone silane linker were suspended in this solution and the pH of the solution was adjusted to 12. After 12 hours, the zinc oxide particles were recovered by centrifugation and dried overnight at 50-60° C. in an oven.

It is also possible to prepare a phosphoether of 4-hydroxybenzophenone and use this self-assembling molecule to functionalize ZnO particles. The resulting particles, having a monolayer of nonpolar molecules, will be substantially nonpolar and will adhere to nonpolar polyester and nylon. In order to bond the particles to the polymer surface an UV light may be used to initiate a reaction. Again, the process has the advantage of adding a second UV absorbing chromophore which cross-links and becomes further bonded to the polymer surface upon exposure to UV light.

The following methods provide for enhanced resistance to degradation of a fabric. The following methods also provide for enhanced resistance to color degradation of a fabric and fiber strength degradation of a fabric. The following methods may also be used to provide enhanced resistance to fire. It is also contemplated that the following methods may also be used on other materials such as leather, faux leather, vinyl, filaments, plastics, plastic components, and molded components. For the purposes of the following methods, the term "fabric" includes leather, faux leather, vinyl, filaments, plastics, plastic components, and molded components. The fabric also has ultraviolet radiation protection incorporated into the fabric. The following methods may be used in the manufacturing process of the fabric.

Example 12

Treating Method

Polyester fabric was treated with ZnO nanoparticles using 3-glycidyloxypropyl-trimethoxysilane linker (GPTMS). The fabric is then cured. By way of example only, the fabric may be heated at 130° C. for a period of time, such as thirty minutes. The fabric is then washed. After curing and washing, the fabric was exposed to UV radiation for 4 hours at an intensity of 4000 $\mu\text{W}/\text{cm}^2$. The fabric was then tested for tensile strength. For control, a polyester fabric was processed at the same conditions but without using ZnO. The tensile strength of the ZnO containing fabric was 10.5 kg as compared to 8.5 kg for the control, showing a significant protection of tensile strength due to the UV blocking provided by ZnO nanoparticles.

Example 13

Dip-Cure-Repeat Method

In this method, the following steps were used for incorporating ZnO onto or into the fabric. Two grams of ZnO nanoparticles were added to 50 ml of GPTMS solution. 1.2 ml of 1-methylimidazol was added as a catalyst for the cross linking reaction of the epoxy group of GPTMS. The resulting suspension was stirred for one hour to ensure that the ZnO

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nanoparticles were well dispersed. A fabric is then dipped into the resulting suspension and cured immediately at 130° C. for thirty minutes. The number of dips of the fabric can be varied from one to four dips.

Example 14

Spray Method

A spray method for incorporating ZnO onto or into fabric includes the following steps. One gram of ZnO nanoparticles was added to 50 ml of GPTMS solution. The suspension was sonicated for one minute to disperse the nanoparticles. 1.2 ml of 1-methylimidazol was added as a catalyst for the cross linking reaction of the epoxy group of GPTMS. The suspension was again sonicated for one minute and transferred into a spray bottle. The suspension was then sprayed onto the fabric at a spraying distance of twelve cm. The fabric was then cured at 130° C. for thirty minutes. The spraying step and the curing step were then repeated for up to four times. The fabric was then laundered and dried.

The ZnO nanoparticles used in Examples 12, 13, and 14 may be made by any of the methods described herein.

From all that has been said, it will be clear that there has thus been shown and described herein a fabric having ultraviolet radiation protection, enhanced resistance to degradation of the fabric, and enhanced resistance to fire which fulfills the various advantages sought therefore. It will become apparent to those skilled in the art, however, that many changes, modifications, variations, and other uses and applications of the subject fabric having ultraviolet radiation protection, enhanced resistance to degradation of the fabric, and enhanced resistance to fire are possible and contemplated. All changes, modifications, variations, and other uses and applications which do not depart from the spirit and scope of the disclosure are deemed to be covered by the disclosure, which is limited only by the claims which follow.

What is claimed is:

1. A method for treating a fabric for ultraviolet radiation protection, enhanced resistance to degradation, and enhanced resistance to fire comprising the steps of:

suspending zinc oxide nanoparticles in a mixture of an aqueous buffer and an organosilane or phosphonate with a reactive group, adding multidentate ligand to form a durable reactive layer on the zinc oxide nanoparticles, and adding an oxide, alkoxide, or salt of a metal other than zinc to form a surface layer of an oxide other than zinc oxide on the zinc oxide nanoparticles;
collecting the zinc oxide nanoparticles by centrifugation;
washing the collected zinc oxide nanoparticles;
re-suspending the zinc oxide nanoparticles in a buffer;
adding the zinc oxide nanoparticles in the buffer to a solution of 3-glycidyloxypropyl-trimethoxysilane;
placing a fabric in the mixture of the zinc oxide particles and 3-glycidyloxypropyl-trimethoxysilane;
curing the fabric;
washing the fabric; and
exposing the fabric to ultraviolet radiation.

2. The method of claim 1 wherein the exposing step comprises the step of exposing the fabric to ultraviolet radiation for a period of four hours.

3. The method of claim 1 wherein the exposing step comprises the step of exposing the fabric to ultraviolet radiation at an intensity of 4000 $\mu\text{W}/\text{cm}^2$.

4. The method of claim 1 wherein the curing step further comprises the step of heating the fabric at 130° C. for thirty minutes.

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5. A method for treating a fabric for ultraviolet radiation protection, enhanced resistance to degradation, and enhanced resistance to fire comprising the steps of:

suspending zinc oxide nanoparticles in a mixture of an aqueous buffer and an organosilane or phosphonate with a reactive group, adding multidentate ligand to form a durable reactive layer on the zinc oxide nanoparticles, and adding an oxide, alkoxide, or salt of a metal other than zinc to form a surface layer of an oxide other than zinc oxide on the zinc oxide nanoparticles;
collecting the zinc oxide nanoparticles by centrifugation;
washing the collected zinc oxide nanoparticles;
re-suspending the zinc oxide nanoparticles in a buffer;
adding the zinc oxide nanoparticles in the buffer to a solution of 3-glycidyloxypropyl-trimethoxysilane;
adding 1-methylimidazol to form a suspension;
stirring the suspension;
dipping a fabric into the suspension; and
curing the fabric immediately after the dipping step.

6. The method of claim 5 wherein two grams of zinc oxide nanoparticles are added to 50 ml of the solution of 3-glycidyloxypropyl-trimethoxysilane.

7. The method of claim 5 wherein the fabric is additionally dipped from two to four times.

8. The method of claim 5 wherein the suspension is stirred for one hour.

9. The method of claim 5 wherein the fabric is cured by heating the fabric at 130° C. for thirty minutes.

10. The method of claim 5 wherein the fabric is additionally dipped from two to four times and the curing step is conducted immediately after each additional dipping step.

11. The method of claim 5 wherein the fabric is dipped an additional three times.

12. A method for treating a fabric for ultraviolet radiation protection, enhanced resistance to degradation, and enhanced resistance to fire comprising the steps of:

suspending zinc oxide nanoparticles in a mixture of an aqueous buffer and an organosilane or phosphonate with a reactive group, adding multidentate ligand to form a durable reactive layer on the zinc oxide nanoparticles, and adding an oxide, alkoxide, or salt of a metal other than zinc to form a surface layer of an oxide other than zinc oxide on the zinc oxide nanoparticles;
collecting the zinc oxide nanoparticles by centrifugation;
washing the collected zinc oxide nanoparticles;
re-suspending the zinc oxide nanoparticles in a buffer;
sonicating the mixture of the zinc oxide nanoparticles in the buffer;
adding 1-methylimidazol to form a suspension;
sonicating the suspension; and
transferring the suspension into a spray bottle, then spraying the suspension from the spray bottle on to a fabric.

13. The method of claim 10 wherein the fabric is cured after being sprayed with the suspension.

14. The method of claim 13 wherein fabric is sprayed and cured up to four times.

15. The method of claim 14 wherein the fabric is washed and dried.

16. The method of claim 12 wherein two grams of zinc oxide nanoparticles are added to 50 ml of the solution of 3-glycidyloxypropyl-trimethoxysilane.

17. The method of claim 12 wherein each of the sonicating steps lasts for one minute.